Bernhard Kokot
Dieter Schwarzenau

A Home-made RF-Millivoltmeter

The authors have designed a RF-millivoltmeter for measuring low to medium RF-voltages. The frequency range, input impedance, and accuracy should be comparable to those of commercially manufactured RF-millivoltmeters.

Since simple rectifier circuits, and rectifier diodes provided with a bias current, are not able to fulfill these demands, the principle of compensation measurement was used.
Fig. 1 shows a photograph of the author's prototype.

1. BLOCK DIAGRAM

The operation of the unit can be seen in the block diagram given in **Figure 2.**

The actual compensation takes place in the probe. It is equipped with a differential rectifier, which also receives an internally generated, low-frequency alternating voltage. The output DC-voltage is proportional to the diffe-

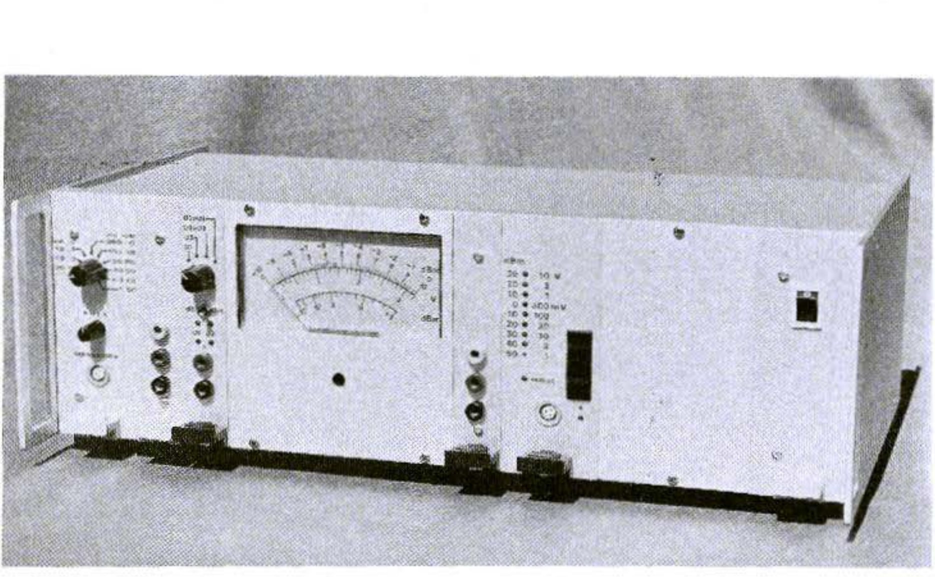


Fig. 1: A photograph of the author's prototype using two AF-modules and a logarithmic amplifier

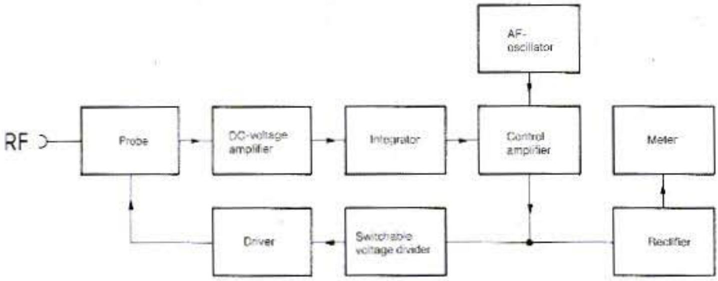


Fig. 2: Block diagram of the RF-millivoltmeter

rence of the peak values of the two alternating voltages.

It is amplified and fed to an integrator, which controls a control amplifier. The control amplifier varies the amplitude of the internally generated AC-voltage. This is fed via a voltage divider to the probe.

In the stationary state, the peak values of the voltage to be measured and the controlled voltage are identical, since the output voltage of the differential rectifier is then zero, and the signal at the output of the integrator will not change.

The internally generated voltage is, however, higher to the value of the division factor of the switchable voltage divider and is constant with respect to frequency. Furthermore, the output impedance of the control amplifier is sufficiently low so that the rectifier connected here can be constructed relatively simply and only needs to be optimized with respect to linearity.

The DC-voltage at the output of this rectifier is then proportional to the peak value of the voltage to be measured. The meter is connected to this position.

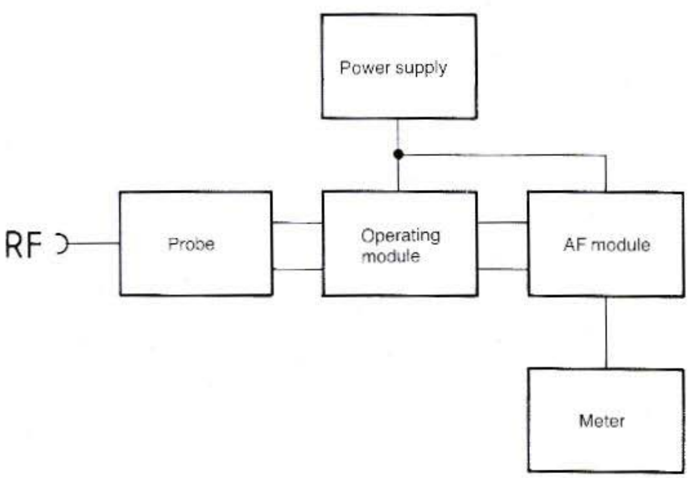


Fig. 3: Individual modules of the millivoltmeter

2. THE INDIVIDUAL MODULES OF THE UNIT

The basic version of the RF-millivoltmeter comprises five modules. This can be seen in **Figure 3.** With the exception of the probe and the meter, all modules are constructed on PC-boards of European standard size.

If a 19 inch cabinet is used, it is possible for the unit to be extended easily. A logarithmic amplifier is available as a sixth module. It can be connected between the meter and two completely constructed basic versions of the RF-millivoltmeter. This allows gain and attenuation values to be measured directly in dB.

Furthermore, the logarithmic amplifier is required if the voltage to be measured is to be indicated lineary in dBm.

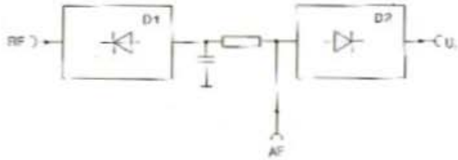


Fig. 4: Principle of the test probes

3. CIRCUIT DESCRIPTION

3.1. Probe

The probe is equipped with two rectifiers that are coupled together. **Figure 4** shows the principle of this circuit. The rectifier D 1 is fed with the AC-voltage to be measured, and charges the capacitor. This DC-voltage is superim-

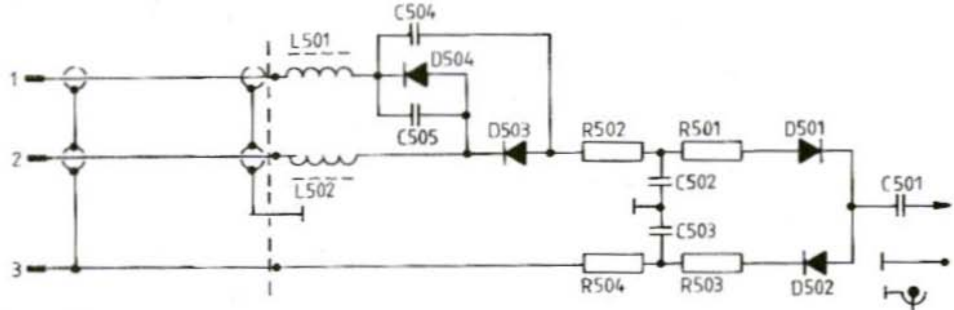


Fig. 5a: Circuit diagram of the test probe DL 0 HV 005

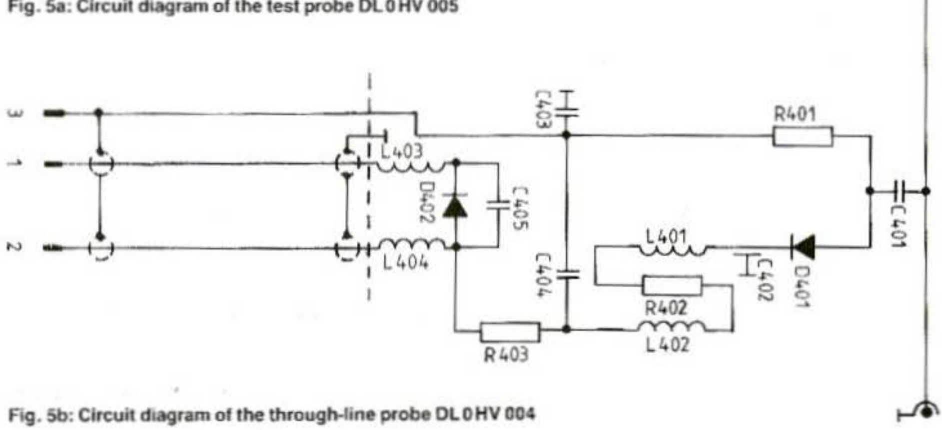


Fig. 5b: Circuit diagram of the through-line probe DL 0 HV 004

posed with the additional AF-voltage and is fed to rectifier D 2. If the peak voltage of the AF-signal is just as great as the DC-voltage, the output voltage of D 2 will be zero.

In all other cases, an offset voltage will result. The operation is therefore independent of the magnitude of the two AC-voltages if the characteristics of the two rectifiers are identical. The shape of the characteristic is primarily unimportant. However, if very low RF-voltages are to be measured, attention should be paid that the rectified voltages are greater than the noise.

Special diodes designed for this application (zero-bias and point-contact diodes) are, however, very expensive. For this reason, experiments were made with conventional germanium diodes. The best results were obtained using cheap germanium point contact diodes, type AA 119. It is possible with these diodes to increase the measuring range of the RF-millivoltmeter down to approximately 1 mV.

In order to avoid thermal voltages from the object to be measured, it is necessary for the rectifier D 1 to be capacitively coupled to the object to be measured. Furthermore, attention should be paid in order to obtain a good, thermal stability so that the characteristic curves do not shift with respect to another due to the difference in temperature.

The complete circuit diagram of the probe is given in **Figure 5a. Figure 5b** shows the circuit diagram of a through-line probe. The construction of both probes is to be described in Section 4.1.

The upper frequency limit of the probes is mainly determined by the capacitance and inductance of the RF-diodes, or their connections. With the described construction and germanium diodes of type AA 119, the cutoff frequency is approx. 1500 MHz (−3 dB).

This could be increased by using special point contact diodes, or zero-bias diodes.

3.2. Control Module

The control module consists of a changeover switch for up to 12 measuring ranges, an input DC-voltage amplifier, and an impedance converter for the AF-supply of the probe. These are available in two versions:

In the case of the first version, the switching is made mechanically using a switch. This switch has three wafers with 12 changeover contacts. Since such switches are relatively expensive, an additional version was designed that uses digitally controlled FETs. Both circuits are to be described.

3.2.1. Control Module with Mechanical Swithing

Figure 6 shows the circuit diagram of the control module with mechanical switching. One will see a DC-voltage amplifier with five digital gain values in the upper part of the circuit diagram. Since the signal coming from the probe can be very low, a chopper amplifier type ICL 7650 was used for this. This integrated circuit behaves exactly as a normal operational amplifier. Actually, it is two amplifiers between which a continuous switching is made.

The amplifier that is not in operation, is always automatically aligned. The offset voltage of the integrated circuit is therefore kept very low.

The field effect transistors T 201 and T 202 serve as over-voltage protection and have a low leakage current. The zero-alignment can be carried out with the aid of P 201. The operational amplifier I 202 serves as impedance converter for the AF-voltage divider, which is switched with the aid of wafer 'c' of the switch. This impedance converter supplies the probe via a transformer.

The transformer is necessary in order to ensure that a sufficiently high AF-amplitude is available for the large measuring range. With wafer 'a' of the switch, a $\frac{1}{\sqrt{10}}$ (10 dB) switching is carried out. This works directly into the AF-module.

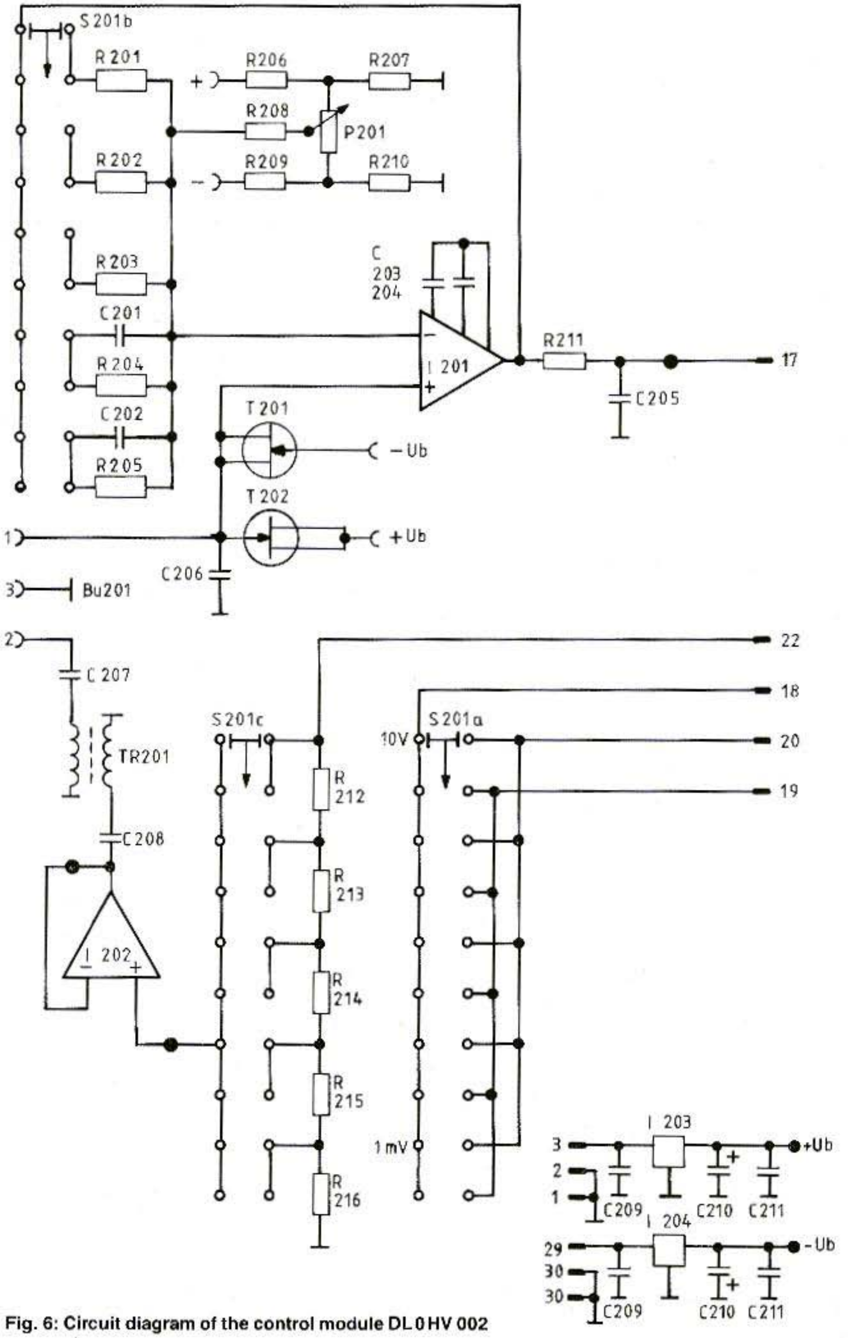


Fig. 6: Circuit diagram of the control module DL0HV 002

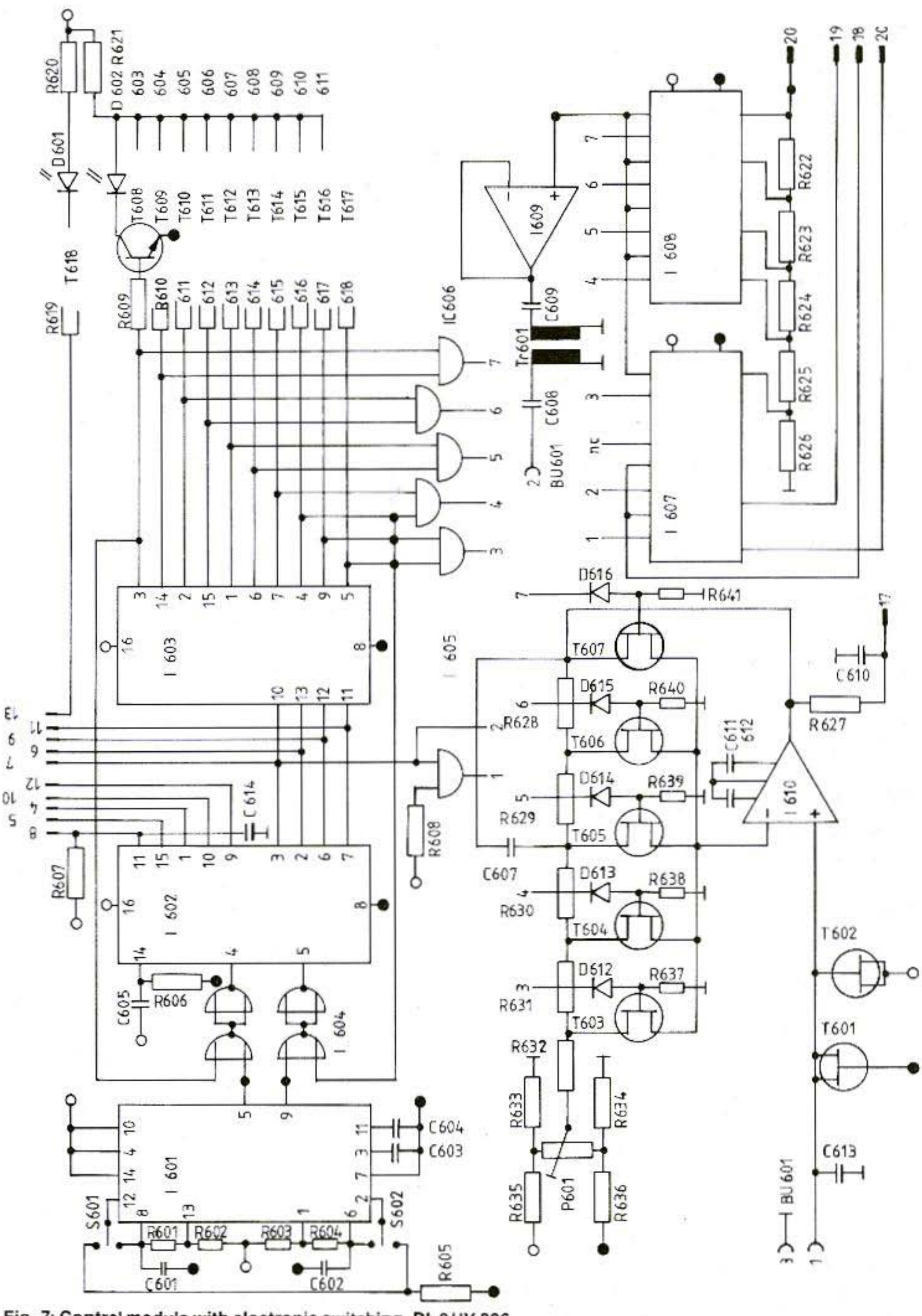


Fig. 7: Control module with electronic switching, DL 0 HV 006

3.2.2. Control Module with Electronic Switching

As can be seen in the circuit diagram given in **Figure 7,** all switching contacts of the mechanical switching are now made with the aid of FETs or MOSFET-switches (I 607, I 608).

These are controlled with the aid of a digital circuit, which is mainly formed by I 602, a binary 4-bit forward-backward counter. The counting impulses drives I 601 that is connected as a dual start-stop-oscillator.

In order to obtain an individual control line for each measuring range, the BCD-signal from I 602 is decoded by I 603, a BCD to decimal decoder. The measuring range is indicated by LEDs D 602-D 611 which are driven by transistors T 608-T 617.

In order to avoid a jumping from the highest to the lowest measuring range, and vice versa, the actual counting input of I 602 is blocked with the aid of NOR-gate (I 604) on reaching the maximum measuring ranges.

Since the lowest measuring range can amount to 3 mV, 1 mV, or 0.3 mV, according to the selection of the diodes in the probe, the possibility was provided of connecting the blocking line for the downward counting to three different outputs of I 603.

Capacitor C 605 together with R 606 provide a reset signal for I 602 after switching on. It is then automatically switched to the highest measuring range.

In addition to the described operation, the integrated counting circuit also allows the possibility to load a counter state directly. The required lines are provided on the connection strip of the module (connections 4-13). This makes it possible to remote-control the unit, or for it to be used together with a computer interface. The remote-control mode is indicated on the control module with the aid of the LED D 601.

CMOS-ICs have been selected for all integrated digital circuits. This deletes the problem of matching the levels to the field effect transistors, and of an additional voltage stabilization. The following should be noted with respect to the operating voltage: Various manufacturers give a maximum operating voltage of 15 V for CMOS-circuits. Philips (Valvo) allow a maximum voltage of 18 V for their circuits! However, no problems were encountered using circuits from other manufacturers.

3.3. AF-Module

The operation of the AF-module can be seen in **Figure 8.**

The DC-voltage signal from the control module is fed to the converting input of I 101. This operational amplifier is switched as an integrator. Its output must be able to be driven down to the negative operating voltage, since the amplitude of the AF cannot be controlled down to zero. For this reason, an operational amplifier type CA 3140 was used here.

In the case of I 102, a so-called OTA (Operational Transconductance Amplifier) is used. This is an operational amplifier whose gain can be adjusted by providing a current in the control input. This control current supplied by the output of the integrator via R 102. It controls the amplitude of the AF, which is generated in an RC-oscillator comprising I 103.

The AF-voltage proportional to the RF-voltage to be measured, is present at the output of the OTA under lock-in conditions. This is fed via C 112 to a very linear rectifier, which is followed by a RC-lowpass filter (R 132/C 116), and an impedance converter. A suitable meter can then be connected to test point TPA.

The rectifier circuit seems to be very extensive at first, however, it offers a great advantage over other circuits in that its operation is independent of the impedance of the meter, and a pure DC-voltage is available at the output. This means that one can also carry out measurements using more accurate, external meters, if a suitable connection is provided.

The controlled AF-signal is fed via C 105 to the amplifier stage equipped with I 104. Its gain can be switched, using the range switch on the control module, from 1 to $\sqrt{10}$ (10 dB switching). This allows one to obtain a suitable range switching.

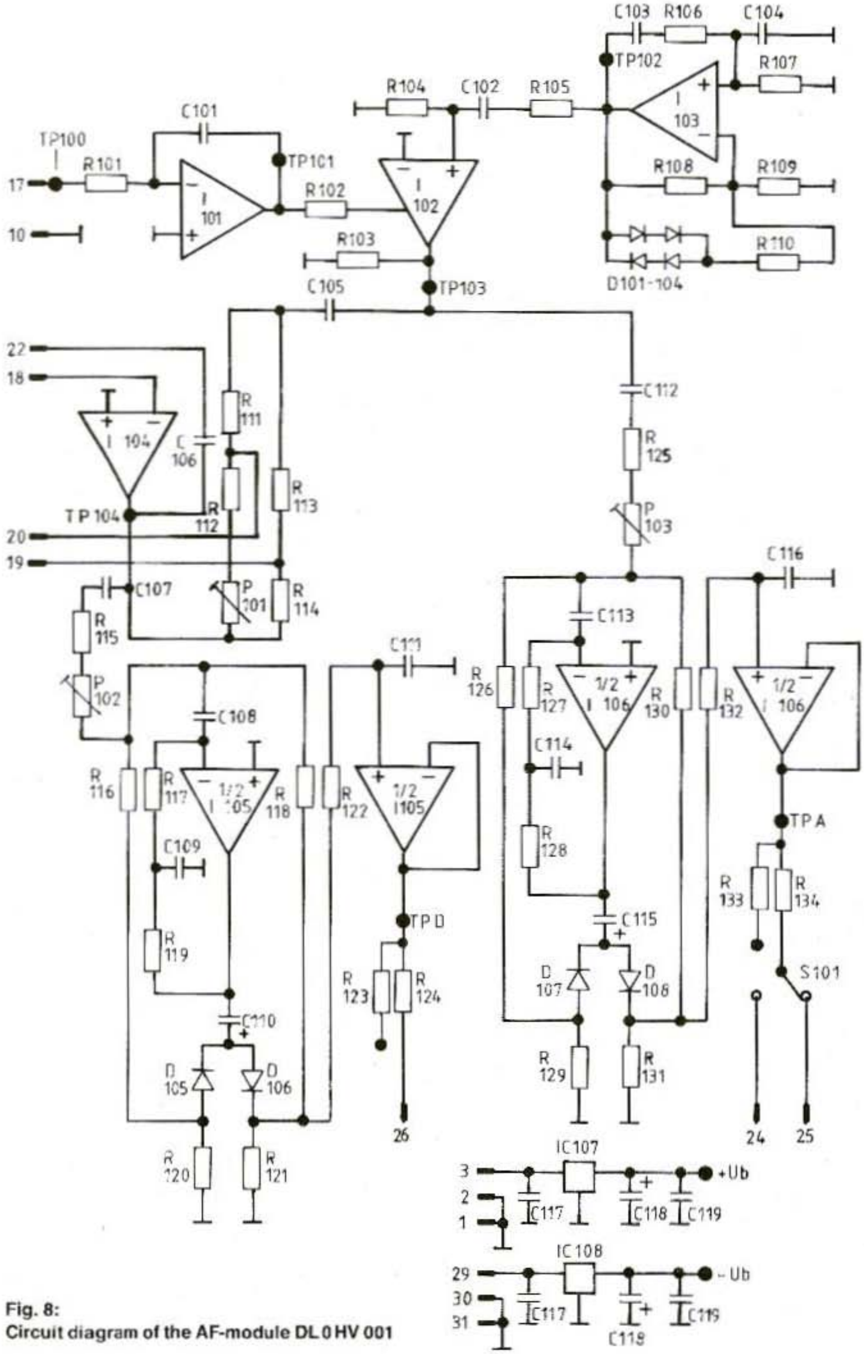


Fig. 8:
Circuit diagram of the AF-module DL 0 HV 001

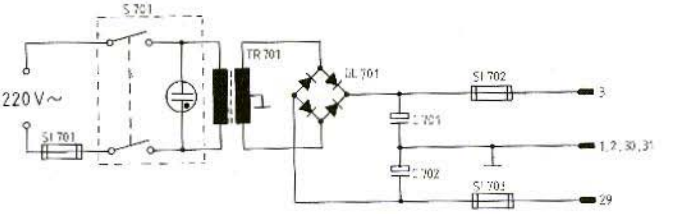


Fig. 9: Circuit diagram of the power supply DL 0 HV 007

A second rectifier is connected to the output of this amplifier stage that is identical to the previously mentioned one. This is provided for the connection of a digital voltmeter. The rectifier equipped with I 106 always provides the same voltage for the full-scale value in each range, independent of the selected gain of I 104, and therefore only two different scales with full-scale values of 1 and 3.16 are required for the analog meter.

On the other hand, a DC-voltage of the corresponding value is required for the connection of a digital voltmeter.

The AF-signal is fed from I 104 via C 106 to the voltage divider and driver stage of the control module.

3.4. Power supply

All described modules are equipped with their own voltage stabilizer circuit. This allows any interference on the supply lines to be effectively suppressed.

In addition to this, a relatively simple circuit can be used as power supply **(Figure 9)**, and no problems are encountered with heat dissipation.

The power supply module only consists of a transformer, rectifier, as well as the associated smoothing capacitors for the positive and negative voltage.

Two fuses are provided for overload protection.

3.5. Meter

The indicator module comprises only a meter, whose full-scale deflection is adjusted to 1 V with the aid of a dropper resistor. It should be provided with two scales having a full-scale value of 10 and $\sqrt{10} = 3.16$.

If the measured voltage is also to be indicated in dBm, this will require a further scale.

If a logarithmic amplifier is available, the indication of dB and dBm will be linear. To read off the voltage in dBm, it is necessary for the upper scale to be additionally provided with a marking from −10 to 0 in the opposite direction. These scales can be seen in **Figure 10.**

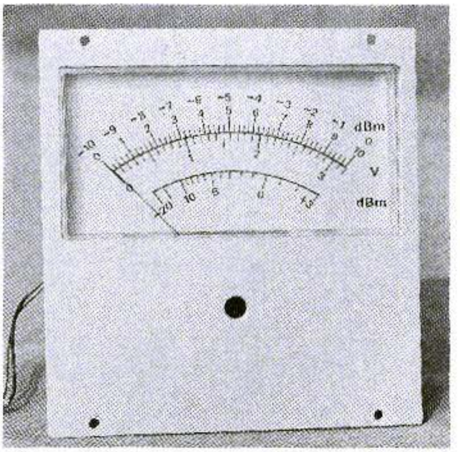


Fig. 10: Meter scales of the author's prototype

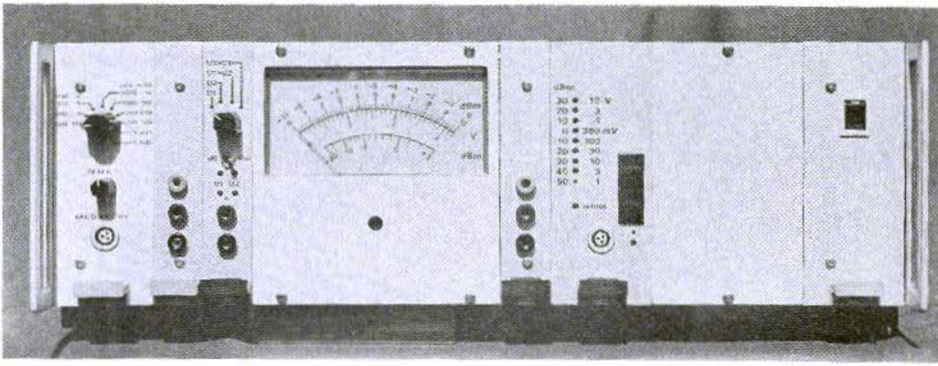


Fig. 11: The completed RF-millivoltmeter in a 19 inch cabinet together with one dummy panel

4. CONSTRUCTION

With the exception of the probes and the indicator module, all other boards of the measuring system are built up using double-coated PC-boards of the standard European format.

All modules are provided with a 31-pin connector strip. This allows the unit to be accommodated in a 19 inch cabinet.

Enough room is provided in the cabinet for extending the instruments. The selected construction allows all modules to be easily accessible. As in the case of the author's prototype (see **Figure 11**), all non-used portions of the cabinet can be covered with a dummy panel.

4.1. Construction of the Probes

Figure 12 shows the two through-line probes, as well as a test probe.

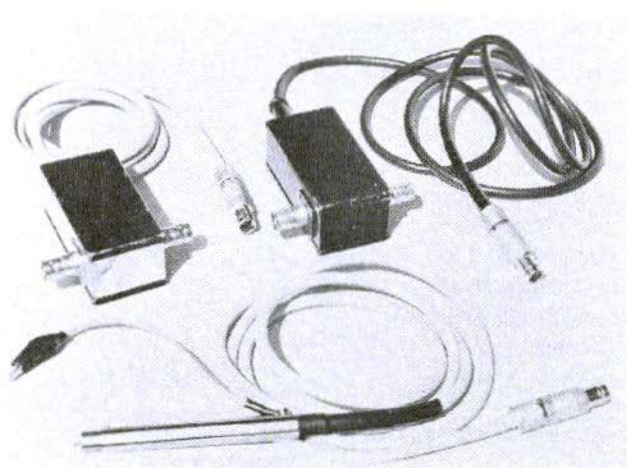


Fig. 12: Test probes for the RF-millivoltmeter

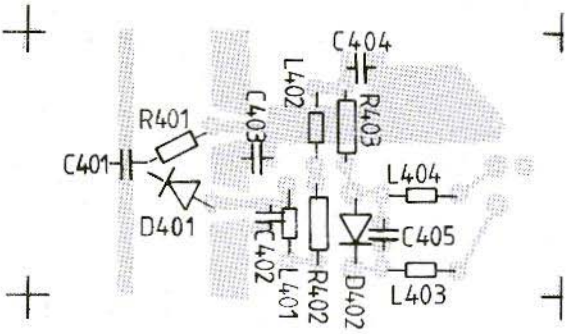


Fig. 13:
Component location plan of PC-board DL0HV 004 (through-line probe)

4.1.1. Through-Line Probe

The through-line probe is accommodated in a metal box, whose dimensions are 37 x 74 x 30 mm. One BNC-connector is provided on each of the wide sides. The cable is fed in to the bottom of the box as shown in Figure 12. The components of the probe are accommodated on a PC-board of 71.5 mm x 34.7 mm; this board is double-coated, and one side is provided as a continuous ground surface **(Figure 13.)** This board is designated DL0HV 004.

Attention should be paid when constructing this module that the chip capacitor C 401 is soldered into place directly on the board. The connections of the BNC-connectors are also directly soldered to the conductor lane.

A screening panel should be provided behind components R 401 and D 401, in order to isolate the AF-side from the RF-circuit. The installation of the other components should be made according to the component location plan given in Figure 13.

Capacitors C 402 to C 404 should, if possible, also be chip-capacitors. The interconnection cable should have three cores two of which must be screened. The components for the through-line probe are given in **Table 1.**

4.1.2. Test Probe

A 9 mm x 68 mm narrow board was developed for accommodating the components of the

Quantity	Designation	Component
2	D 401, D 402	Diode AA 119 (BAT 16, GD 741)
1	R 402	Resistor 47 Ω
1	R 401	Resistor 4.7 kΩ
1	R 403	Resistor 47 kΩ
1	C 405	Capacitor 100 pF / ceramic
4	C 401 – C 404	Capacitor 1 nF / ceramic
2	L 401, L 402	Fixed inductance 1 μH
2	L 403, L 404	Fixed inductance 10 μH
1	–	Metal box 30 x 37 x 74 mm
2	–	BNC connectors
–	–	Cable 4-core, individually screened
1	–	Double-coated board DLØHV 004, 34.7 x 71.5 mm

Table 1:
List of components for the through-line probe

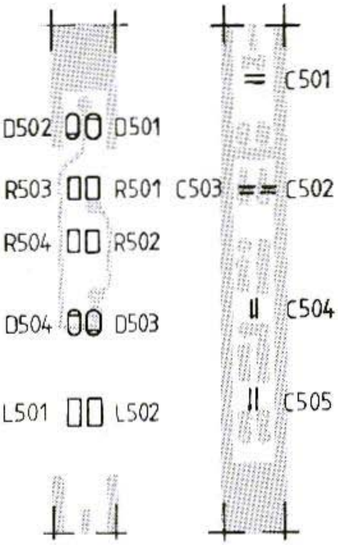


Fig. 14:
PC-board DL0HV 005 for the test probe

test probe, (see **Figure 14**). It is double-coated and has been designated DL0HV 005. It can be mounted in any suitable metal box. Attention should be paid that the interconnection of the test probe to the first rectifier is kept as short and as low-capacitance as possible.

In the case of the author's prototype, the completed PC-board was built into a brass tube having an inner diameter of 9 mm. Special attention was paid to obtain a simple construction.

As was already mentioned in the operational description, it is very important with respect to the measuring accuracy that the characteristic curves of the two diodes used, coincide as well as possible. The selected diodes should therefore be from the same production run. If this is not possible, it is necessary for the diodes to be selected – this is also valid for the through-line probe!

Of course, it is possible for diodes specially developed for RF-measuring equipment to be used instead of the diodes type AA 119. Such diodes are the BAT 16 or GD 741 manufactured by Siemens. These are suitable for higher frequencies, but also have a far higher price.

Table 2 contains a list of the components for this test probe.

4.2. Construction of the other Modules

As has been previously mentioned, all PC-board modules with the exception of the probe boards, are built in standard European size, and equipped with their own 31-pin connector strip. Double-coated PC-boards are used for the AF-module, control module, and logarithmic amplifier. A single-coated PC-board was designed for the power supply. Each board is provided with its own front panel, whose dimensions are 25.4 or 50.8 mm in width.

Quantity	Designation	Component
4	D 501 – D 504	Diode AA 119 (BAT 16, GD 741)
2	R 501, R 503	Resistor 180 Ω
2	R 502, R 504	Resistor 10 kΩ
1	C 505	Chip capacitor 100 pF
3	C 501 – C 503	Chip capacitor 1 nF
1	C 504	Chip capacitor 22 nF
2	L 501, L 502	Fixed inductance 10 μH
1	–	Double-coated board DLØHV 005, 9 x 68 mm
–	–	Cable 4-core, individually screened
1	–	Casing

Table 2:
List of components for the test probe

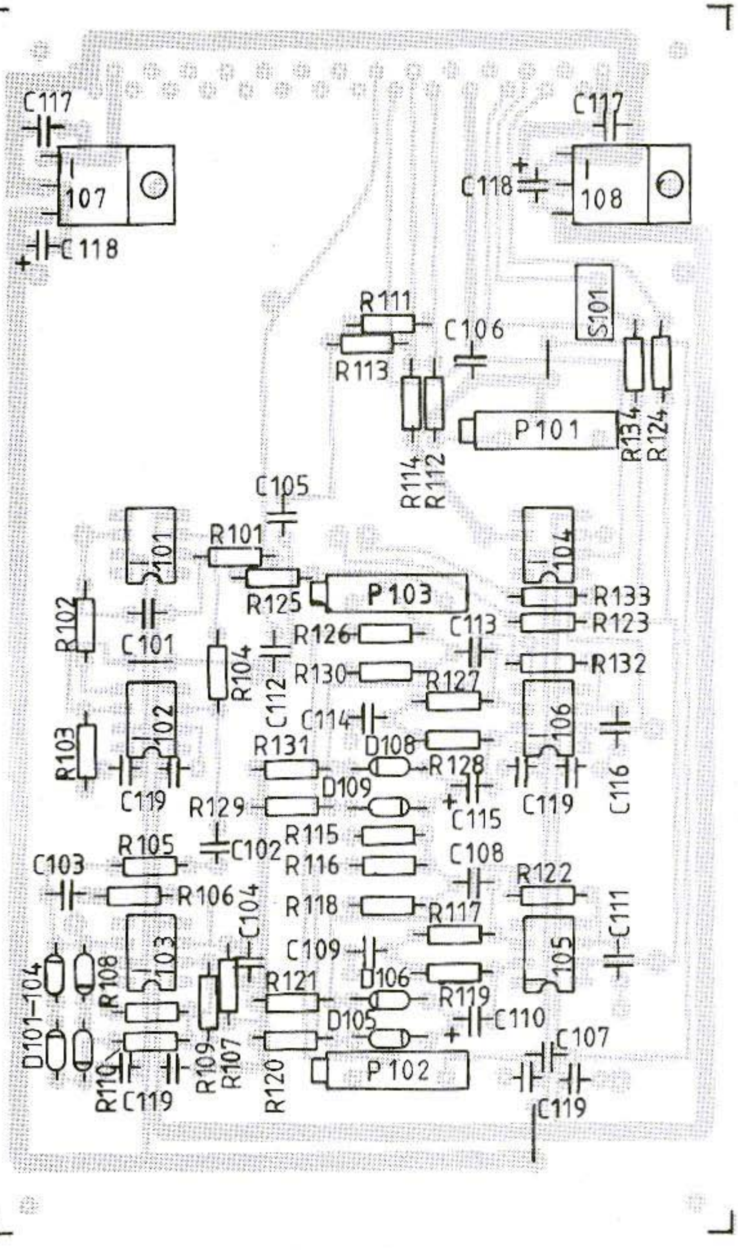


Fig. 15: Component locations of the AF-module DL0HV 001

4.2.1. AF-Module

Figure 15 shows the component locations on the double-coated PC-board DL0HV 001. The component side of this board is provided with a continuous ground surface, and this is drilled free for those connections that are not connected to ground. **Figure 16** shows a photograph of a completed board. The required components are given in **Table 3.** The rectifier circuit comprising I 105 need only be provided when an output for a digital voltmeter is required.

The AF-module is provided with a 1 inch-front panel, whose dimensions are given in **Figure 17.** It is connected to the PC-board with the aid of a bracket. It is not necessary to provide any markings on the front panel.

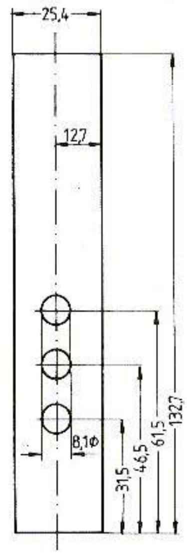


Fig. 17: Front panel of the AF-module

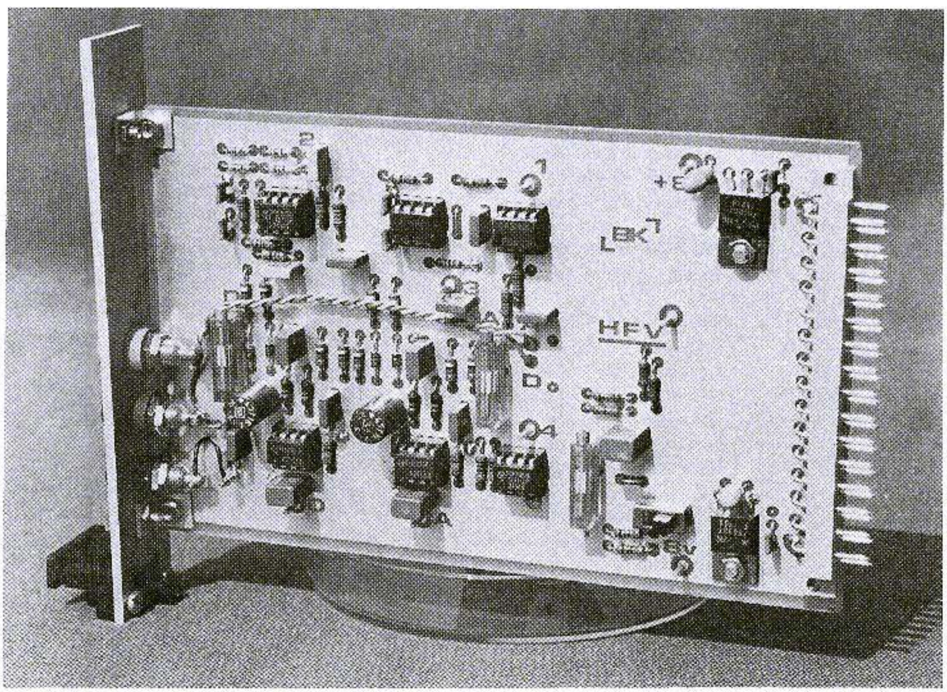


Fig. 16: Photograph of a completed AF-module

Quantity	Designation	Component
4	D 101 – D 104	Diode 1N 4148
4	D 105 – D 108	Diode HSCH 1001
1	I 101	CA 3140 E
1	I 102	CA 3080 E
2	I 103, I 104	TL 071 CP
2	I 105, I 106	TL 072 CP
1	I 107	MC 7808 CT
1	I 108	MC 7908 CT
4	R 123, R 124 R 133, R 134	Resistor 100 Ω
1	R 104	Resistor 150 Ω
1	R 103	Resistor 2.7 kΩ
2	R 106, R 107	Resistor 4.7 kΩ
1	R 102	Resistor 5.6 kΩ
5	R 105, R 109 R 111, R 113 R 114	Resistor 10 kΩ
1	R 125	Resistor 12 kΩ
1	R 108	Resistor 22 kΩ
1	R 112	Resistor 30 kΩ
9	R 115, R 116 R 118, R 120 R 121, R 126 R 129 – R 131	Resistor 39 kΩ
1	R 110	Resistor 82 kΩ
1	R 101	Resistor 100 kΩ
2	R 122, R 132	Resistor 470 kΩ
4	R 117, R 119 R 127, R 128	Resistor 1 MΩ
2	C 103, C 104	Capacitor 4.7 nF / FKC
2	C 108, C 113	Capacitor 10 nF / MKS
4	C 102, C 105 C 107, C 112	Capacitor 100 nF / MKS
10	C 117, C 119	Capacitor 100 nF / ceramic
4	C 101, C 109 C 114	Capacitor 220 nF / MKS
2	C 111, C 116	Capacitor 680 nF / MKS
1	C 106	Capacitor 1 μF / MKS
2	C 118	Capacitor 10 μF, 16 V / tantalum
2	C 110, C 115	Capacitor 47 μF, 16 V / tantalum
2	P 101, P 102	Potentiometer 10 kΩ (call 0613/300)
1	P 103	Potentiometer 4.7 kΩ (call 0613/300)
1	S 101	MFP 120 Knitter Switch
1	–	Connector strip 31-pin, DIN 41617
1	–	Front panel 1 inch Vero F1V1F
3	–	Telephone jacks insulated
–	–	Solder pins
–	–	Screws and nuts
2	–	Mica disk for TO 220
1	–	PC-board DLØHV 001, 100 x 160 mm, double-coated

Table 3: List of components for the AF-module

To be concluded in ed. 3/1984

Bernhard Kokot,
and Dieter Schwarzenau

A Home-Made RF-Millivoltmeter Second, concluding part

4.2.2. Mechanically-switched Control Module

This double-coated PC-board has been designated DL0HV 002. **Figure 18** shows the component locations on this board and **Figure 19** a photograph of the author's prototype. **Table 4** gives all required components. The two inch wide front panel is drilled as shown in **Figure 20.**

4.2.3. Electronically-switched Control Module

This module comprises the electronic board DL0HV 006a (Euroboard) and a control board DL0HV 006b (see **Figure 22**), whose dimensions are 40 mm x 100 mm. It is mounted behind the two inch front panel as shown in **Figure 23.** A photograph of the author's prototype is given in **Figure 24.**

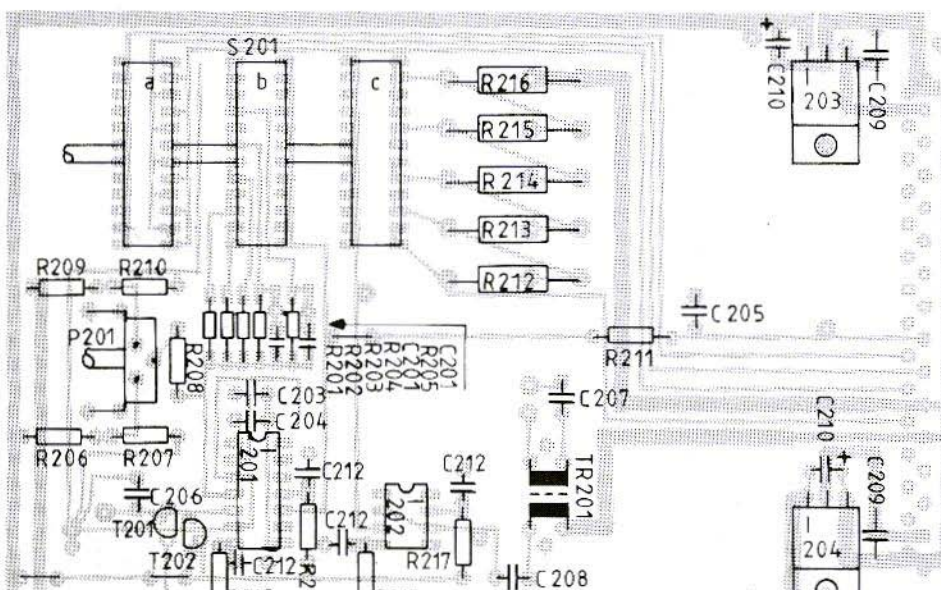


Fig. 18: Components of the control module (mechanical) DL0HV 002

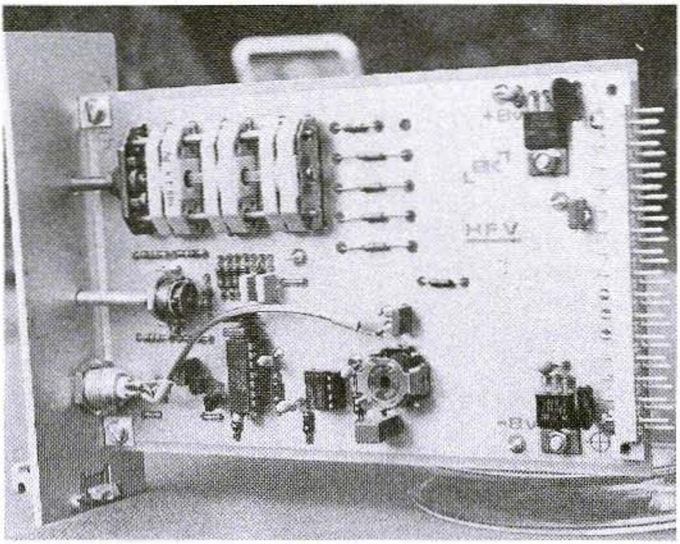
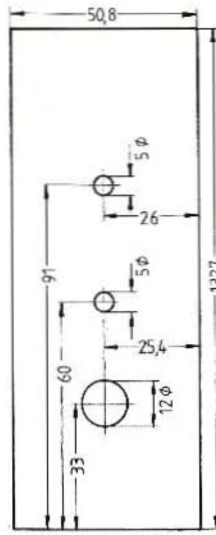


Fig. 19: Photograph of the author's prototype control module with mechanical switching



All dimensions in mm

Fig. 20:
Front panel for the mechanically-switched control module

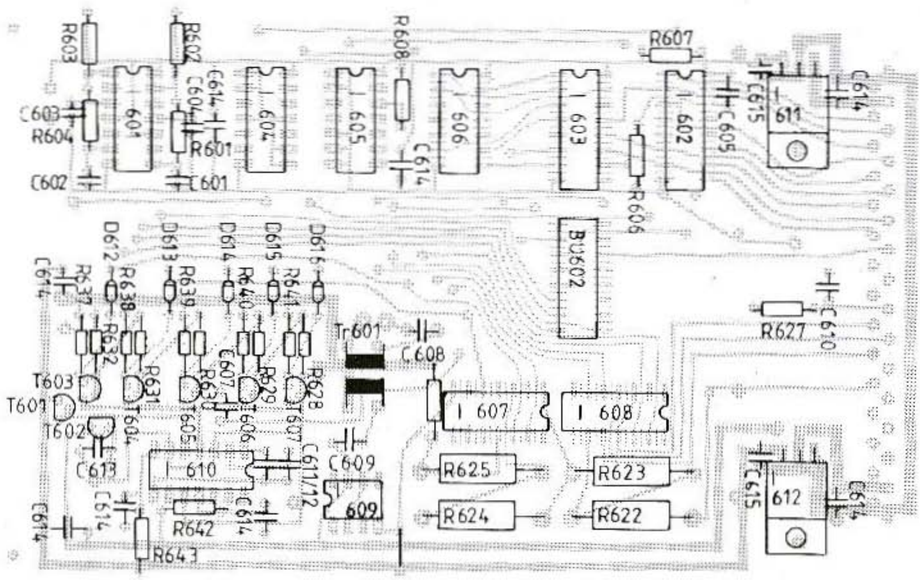


Fig. 21: Components of the electronic board DL 0 HV 006a for the electronically-switched control module

Quant.	Designation	Component
1	I 201	ICL 7650 CPD (Intersil)
1	I 202	TL 071 CP
1	I 203	MC 7808 CT
1	I 204	MC 7908 CT
2	T 201, T 202	BF 256
2	R 207, R 210	Resistor 1 Ω
1	R 216	Resistor 10 Ω
1	R 215	Resistor 90 Ω
4	R 217	Resistor 100 Ω
1	R 214	Resistor 900 Ω
2	R 201, R 208	Resistor 1 kΩ
1	R 213	Resistor 9 kΩ
2	R 202, R 211	Resistor 10 kΩ
1	R 212	Resistor 90 kΩ
1	R 203	Resistor 100 kΩ
3	R 204, R 206 R 209	Resistor 1 MΩ
1	R 205	Resistor 10 MΩ
1	C 208	Capacitor 1 μF / MKS
2	C 201, C 202	Capacitor 1 nF / FKC
2	C 206, C 207	Capacitor 22 nF / MKS
2	C 203, C 204	Capacitor 100 nF / MKS
7	C 205, C 209 C 212	Capacitor 100 nF / ceramic
2	C 210	Capacitor 10 μF / tantalum
1	P 201	Potentiometer 100 Ω
1	TR 201	Potted core 14 x 8, Al 2100 (Siemens) with coil former and mounting plate 1.) 300 turns; 2.) 75 turns enamelled copper wire 0.1 mm dia.
1	S 201	Switch SBL 11.3 x 12
1	BU 201	Connector
1	–	31-pin connector DIN 41617
1	–	Front panel 2 inch / Vero F2V1F
1	–	Knob for 6 mm dia. shaft
2	–	Mica disks for TO 220
–	–	Screws and nuts
–	–	Solder pins
1	–	PC-board DL0HV 002, 100 x 160 mm, double-coated

Table 4: Components list for the mechanically-switched control module

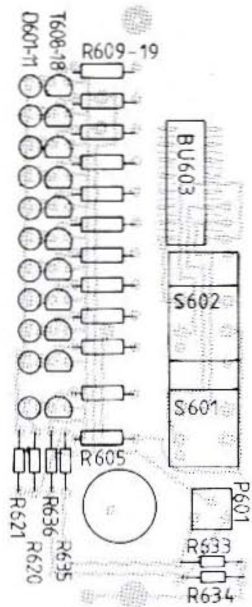


Fig. 22: Component locations of the control board DL0HV 006b for the electronically-switched control module

All dimensions in mm

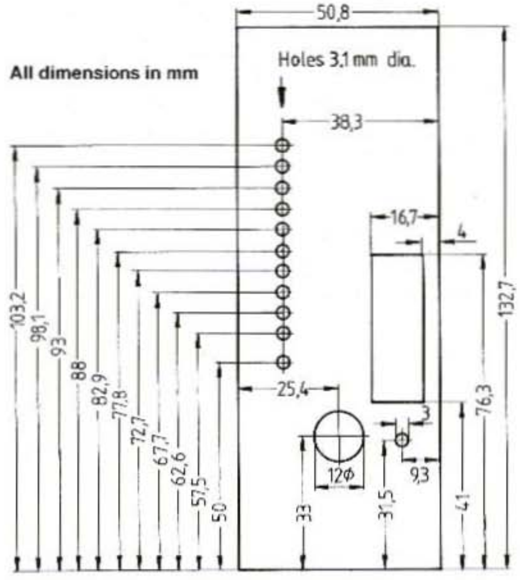


Fig. 23:
Front panel for the electronically-switched control module

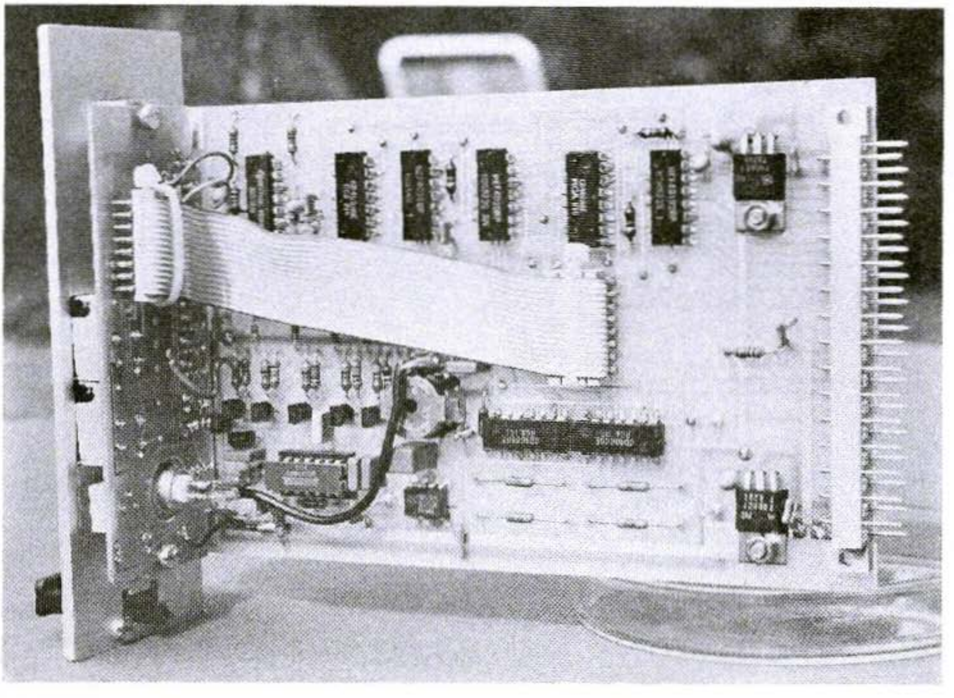


Fig. 24: Photograph of the electronically-switched control module DL0HV 006a + b

Two aluminium blocks of 10 mm per side are provided with a threaded hole of 3 mm diameter and are used for mounting the control board DL0HV 006b behind the front panel. It is fixed to the rear side of the front panel with the aid of a metal adhesive. The electrical connections to the electronic board DL0HV 006a are made via a 16-pole flat cable with DIL connectors at each end, and several additional wires. **Table 5** gives all required components:

4.2.4. Power Supply

As previously mentioned, the PC-board for the power supply is only single-coated and has been designated DL0HV 007. **Figure 25** shows the components on this PC-board; in the photograph of the open power supply **(Figure 26)** one will see the toroid-core transformer, as well as the temporarily used toroid-core choke, and the charge capacitors C 701 and C 702 formed from two parallel-connected capacitors. All required parts are given in **Table 6.**

Quant.	Designation	Component
11	D 601 – D 611	LED LD 350-4
5	D 612 – D 616	Diode 1 N 4148
2	T 601, T 602	FET BF 256
5	T 603 – T 607	FET BF 245 C
10	T 608 – T 617	Transistor BC 237 B
1	I 601	NE 556 N
1	I 602	HEF 40192 BP
1	I 603	HEF 4028 BP
1	I 604	HEF 4001 BP
2	I 605, I 606	HEF 4030 BP
2	I 607, I 608	CD 4066 BE
1	I 609	TL 071 CP
1	I 610	ICL 7650 CPD
1	I 611	MC 7808 CT
1	I 612	MC 7908 CT
2	R 633, R 634	Resistor 3.9 Ω
1	R 626	Resistor 10 Ω
1	R 625	Resistor 90 Ω
2	R 620, R 621	Resistor 820 Ω
1	R 624	Resistor 900 Ω
1	R 632	Resistor 1 kΩ
1	R 623	Resistor 9 kΩ
8	R 601, R 604 – R 608 R 627 – R 631	Resistor 10 kΩ
16	R 609 – R 619 R 637 – R 641	Resistor 47 kΩ
2	R 602, R 603	Resistor 82 kΩ
1	R 622	Resistor 90 kΩ
1	R 630	Resistor 100 kΩ

3	R 629, R 635 R 636	Resistor 1 MΩ
1	R 628	Resistor 10 MΩ
1	C 607	Capacitor 1 nF / FKC
2	C 608, C 613	Capacitor 22 nF / MKS
2	C 611, C 612	Capacitor 100 nF / MKS
9	C 610, C 614	Capacitor 100 nF / ceramic
1	C 609	Capacitor 1 μF / MKS
4	C 601 – C 604	Capacitor 2.2 μF, 25 V / tantalum
2	C 607, C 615	Capacitor 10 μF, 16 V / tantalum
1	Tr 601	Potted core 14x8, AL 2100 with coil former and mounting support pr.: 75 turns; sec.: 300 turns 0.1 mm dia. enammelled copper wire
1	Bu 601	connector
2	Tast S 601, Tast S 602	Digitaster, black
2	–	DIL sockets 16-pole
2	–	DIL connectors, 16-pole
–	–	flat cable, 16-core
1	–	31-pin connector DIN 41617
1	–	Front panel 2'' Vero F2V1F
2	–	Aluminium block 10 x 10 x 10 mm
1	–	PC-board DL 0 HV 006, 100 x 160 mm, double-coated
1	–	PC-board 40 x 100 mm, double-coated
2	–	Mica disks for TO 220
–	–	Solder pins
–	–	Screws and nuts M3

Table 5: Components list for the electronically-switched control module

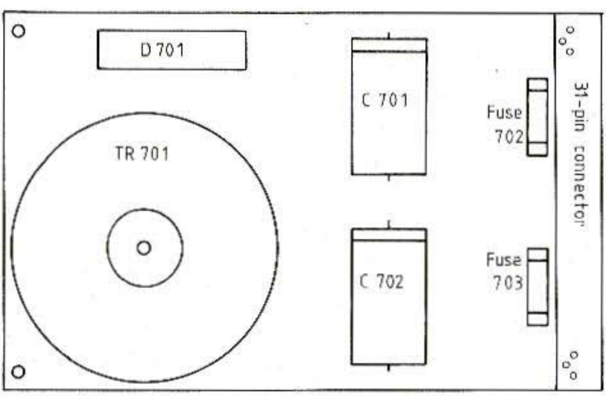


Fig. 25: Component locations on the power supply board DL 0 HV 007

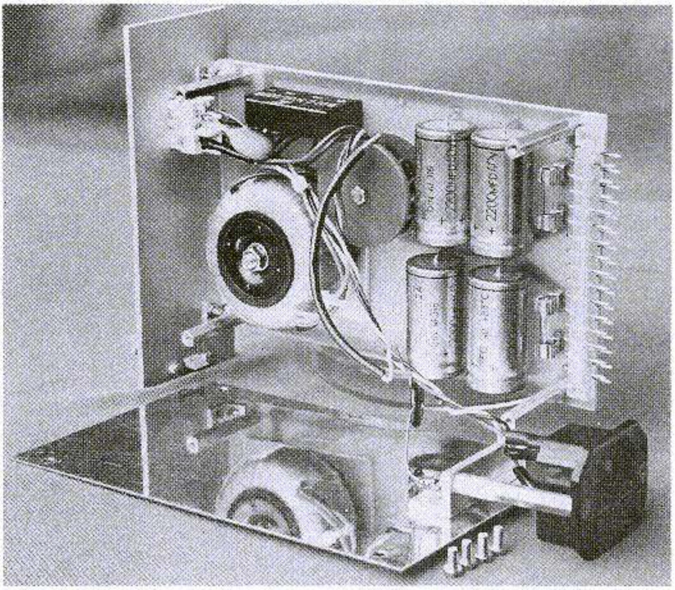


Fig. 26: Photograph of the open power supply module

Quant.	Designation	Component
1	–	PC-board DL 0 HV 007, 100 x 160 mm single-coated
1	Tr 701	Toroid core transformator 2 x 12 V / 20 VA
2	C 701, C 702	Elektrolytic capacitor 4700 μF / 40 V
2	–	Fuse holder for PC-board mounting
2	Si 702, Si 703	Fuses 1 A, inert
1	Gl 701	Rectifier B40C3200
1	–	Two-inch front panel Vero F2V1F
1	S 701	Power switch with lamp
1	–	Power connector with fuse
1	Si 701	Fuse 0.1 A, quick-action
1	–	31-pin connector DIN 41617
1	–	Cover 100 x 160 mm
1	–	Aluminium bracket 10x15x45 mm
2	–	Spacers M3 x 40
4	–	Spacers M3 x 37
–	–	Screws M3 and spring washers
–	–	Insulating tubing

Table 6: Components list for the power supply

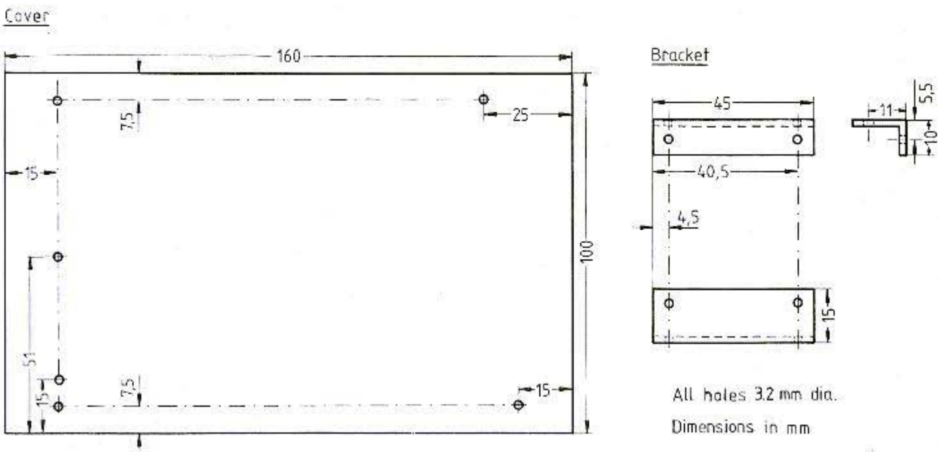


Fig. 27: Mechanical parts for constructing the power supply module

A completely insulated construction was used for feeding in the power supply voltage. The author constructed a cover plate and a bracket as shown in **Figure 27.** The cover plate was connected to the board using four spacers of 37 mm in length. The power connector with built-in fuse is connected to the bracket using two further, 40 mm long spacers. After screwing the bracket to the cover plate, it is possible for the interconnection to be made between the power supply and power connector. If the interconnection points are covered with insulating tubing, sufficient attention will have been paid to avoid electrical shock.

In order to ensure that the power connector is accessible from behind, it is necessary for a cutout to be provided in the rear panel of the unit, whose dimensions are given in **Figure 28.** The 2 inch wide front panel for the power supply plug-in is finally shown in **Figure 29.**

4.3. Installation into the Cabinet

31-pole connectors (DIN 41617) are installed into the plug-in cabinet at the required positions. At the same time, solder tags are mounted simultaneously with the screws, which are then connected to connections 1 and 31 in order to provide the required ground connections.

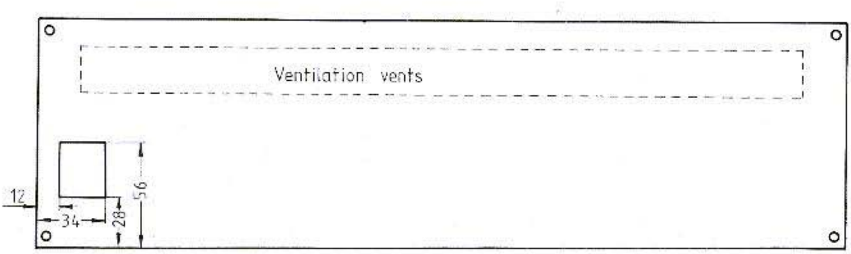


Fig. 28: Cutout on the rear panel of the cabinet

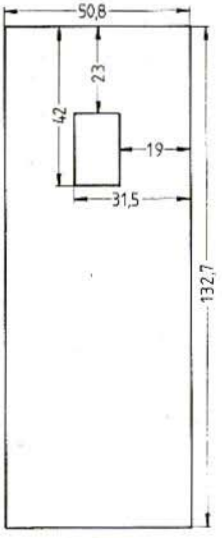


Fig. 29: Dimensional drawing for the front panel of the power supply

Finally, the power supply lines are provided in the cabinet, and soldered to connections 3 and 29 of each connector strip.

The following interconnections are required between the control and AF-module: Connections 17, 18, 19, 20, and 22.

The output of the AF-module – either connection 24 or 25 according to the position of S 101 – is connected to the corresponding input of the logarithmic circuit.

5. ALIGNMENT

The alignment can be made after the described modules have been constructed and wired together.

Firstly, check whether the RC-oscillator of the AF-module is operating correctly. An AC-voltage of approx. 1.5 V RMS should be present at test point TP 102 with a frequency of 7.5 kHz. If this voltage is too low, it may be necessary to change the values of capacitors C 103 and C 104. The frequency of 7.5 kHz is not critical.

For the actual alignment, the circuits should be connected as shown in **Figure 30.** Any available transmitter can be used as signal source. It should only be able to provide a signal of sufficient, and constant amplitude.

The attenuator, or output voltage of the signal source should be adjusted so that a DC-voltage of 4.47 V is measured after the Schottky diode.

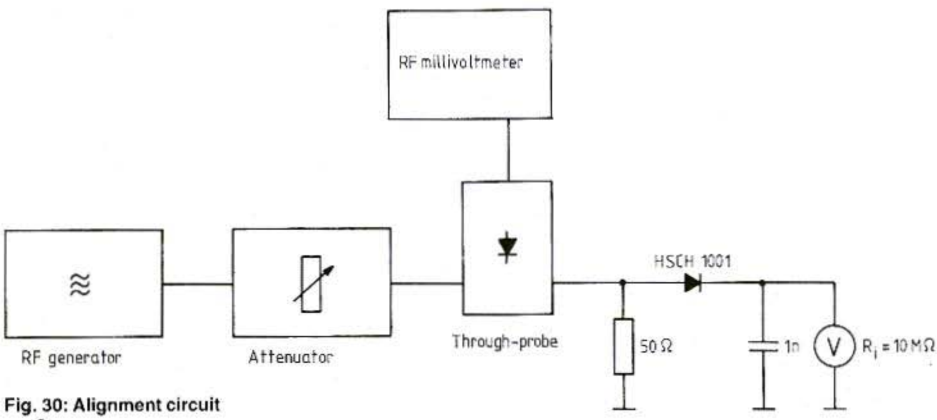


Fig. 30: Alignment circuit

Set the RF-millivoltmeter to its 3 V range and connect a meter to testpoint A of the AF-module. Align P 103 to obtain a voltage of 1 V at this testpoint (full scale).

Finally, an output voltage of 0.316 V is aligned with the aid of P 101 in the 10 V measuring range. If the same meter is used for alignment that is to be used in the indicator module, and if it possesses two scales, this indication will correspond to the same value, but on the other scale.

The 10 V measuring range is also selected for alignment of the digital voltmeter output. P 102 is aligned so that the same voltage is present at testpoint D as at testpoint A.

6. EXTENSIONS

6.1. Logarithmic Circuit

The logarithmic circuit to be described represents a useful extension to the RF-millivoltmeter. It is possible using this module to read off voltages or attenuation values directly in dBm or dB on the linear scale of the meter. It is only necessary for the meter to be marked in the opposite direction from −10 to 0 for the dBm-indication.

The logarithmic circuit is connected in front of the meter. It possesses two inputs between which one can switch (voltage measurement), or which are both used for measurements of voltage ratios (attenuation or gain).

6.1.1. Principle of the Logarithmic Circuit

Most known logarithmic circuits use the exponential characteristics of diodes or transistors with the aid of operational amplifiers. The disadvantages of this principle are the complicated alignment, and the large temperature drift. For this reason, a different method was used here, which utilizes the discharge curve of a capacitor to obtain the exponentional characteristic.

Figure 31 shows the principle used together with the most important components, and the associated characteristic curve. Switch S is closed with a certain fixed frequency in order to charge capacitor C to a voltage U_1, after which it opens.

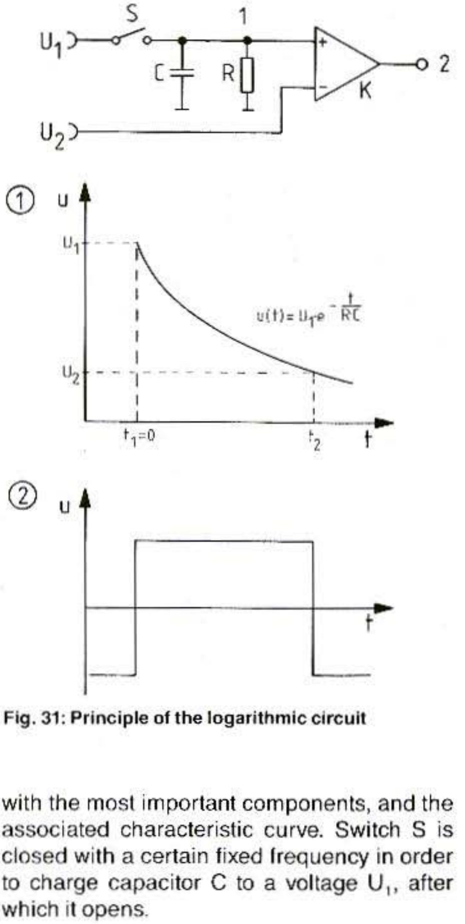


Fig. 31: Principle of the logarithmic circuit

Since U_1 is greater than U_2, the output of comparator K will become positive at the same time. The capacitor will now discharge itself via resistor R. The voltage can now be calculated according to the following equation:

$$u(t) = U_1 \times e^{-\frac{t}{R \times C}}$$

When the value of U_2 is reached, the comparator will switch, and the voltage at its output will be negative again.

If the corresponding values for this condition are placed into the equation, and if it is resolv-

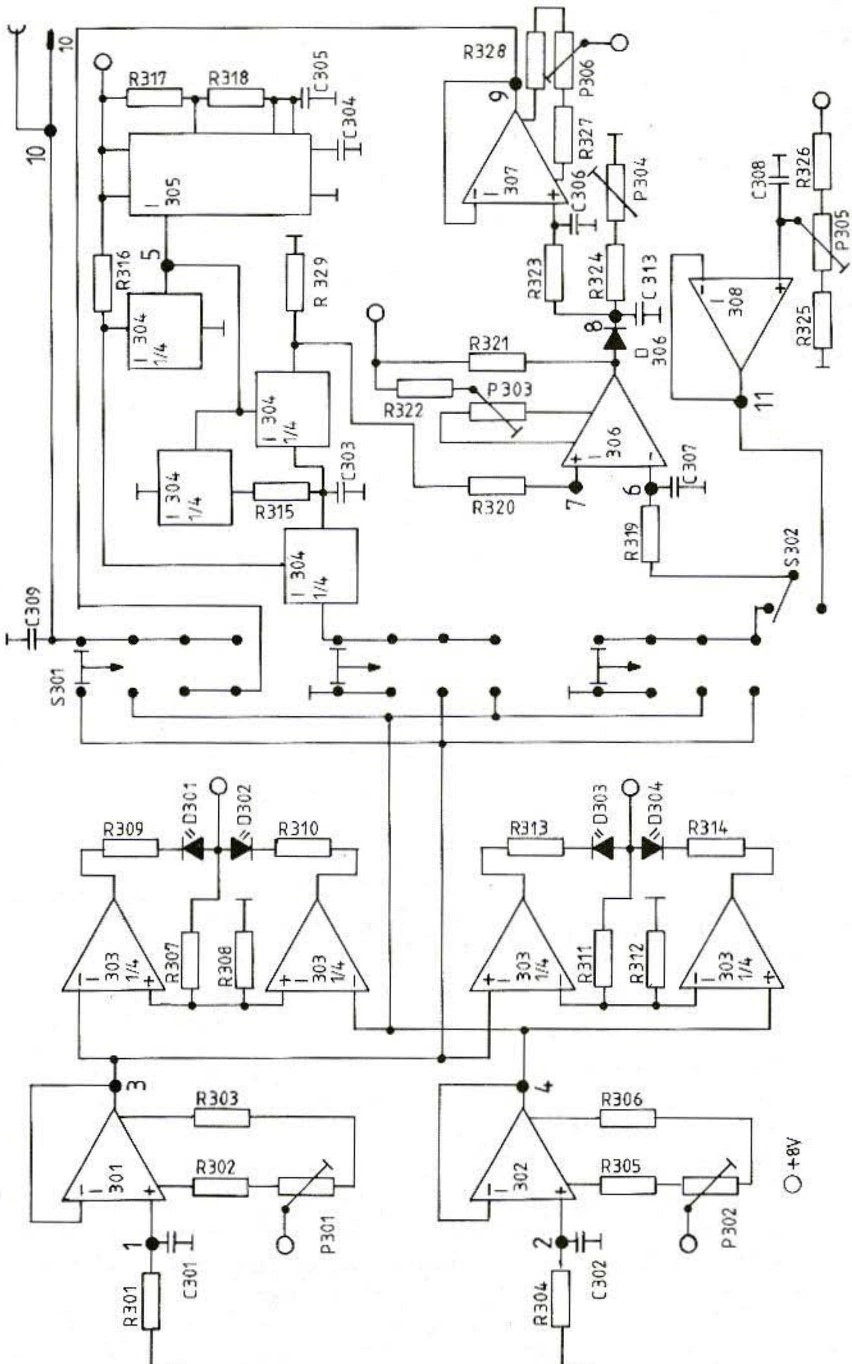


Fig. 32: The logarithmic circuit

ed according to the delay time, the following will result:

$$t_2 = R \times C \times \ln \frac{U_1}{U_2}$$

The pulse width of the voltage at the output of the comparator is therefore a measure of the logarithmic relationship between the two input voltages. A corresponding DC-voltage is obtained for the meter by forming the mean value of the signal.

6.1.2. Logarithmic Circuit

The circuit of the logarithmic module is given in **Figure 32.**

The two inputs are buffered with the aid of operational amplifiers (I 301 and I 302). The LEDs connected to the four comparators (I 303) indicate when the voltages are too high or too low, and that another measuring range should be selected.

It is possible for the various operating modes to be selected with the aid of the four-position switch S 301. In the two upper positions, one of the input voltages is directly indicated on the meter connected to connection 10. In the other positions, these voltages are passed via the logarithmic circuit.

The switch position should be selected at which the lower of the two voltages is present at the inverting input of the comparator (I 306). With the aid of S 302, it is possible for this voltage to be replaced by a fixed voltage as provided by I 308. This is necessary, if individual voltages are to be measured in dBm.

The actual logarithmic circuit differs from that described in the previous section in that it possesses one additional switch, each, in the discharge path, and subsequent to the capacitor. These are necessary because the MOS-FET switches used here exhibit a resistance which cannot be neglected when they are conducting, since this would form a voltage divider in conjunction with the discharge resistor. Furthermore, this means that the charge time for the capacitor cannot be kept as short as required, which means that the comparator must be disconnected from the capacitor during this period.

The switches are controlled from a timer IC (I 305), which is connected as multivibrator. It generates a square-wave signal with a keying ratio of 4.5:1 at a frequency of approx. 750 Hz.

The output signal of the comparator is fed via

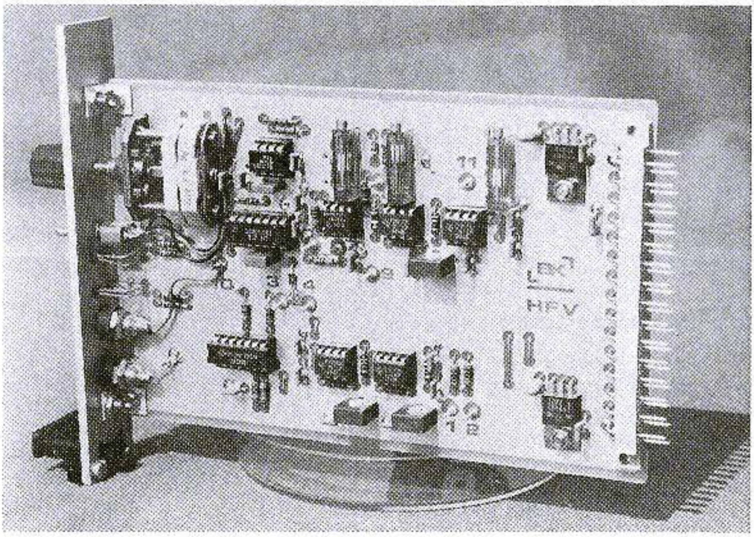


Fig. 33: Photograph of the author's prototype logarithmic module

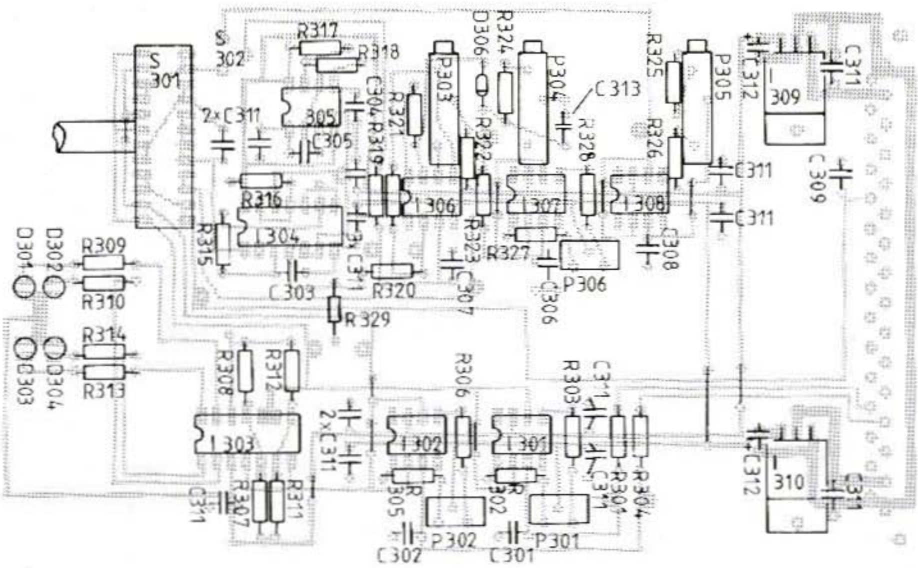


Fig. 34: Components on the logarithmic board DL0HV 003

a diode (D 306) to a low-pass filter for forming the mean value.

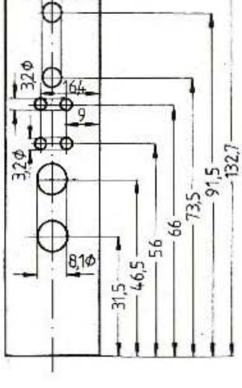
The required DC-voltage signal is available at the output of I 307 and is fed to a meter.

6.1.3. Construction of the Logarithmic Circuit

A double-coated PC-board (Eurocard size) has been developed for accommodating the logarithmic circuit **(Figure 33).** This board is designated DL0HV 003 and should be equipped according to the component location plan given in **Figure 34.** The components are listed in **Table 7:**

6.1.4. Alignment of the Logarithmic Circuit

For alignment of the logarithmic circuit, the two inputs should be connected together and grounded. The offset of the two input amplifiers can be aligned with the aid of trimmer potentiometers P 301 and P 302 and read off with the aid of a voltmeter connected to points 3 and 4.



All dimensions in mm

Fig. 35: Front panel of the logarithmic module

Table 7: Components list for the logarithmic module

Quant.	Designation	Component
4	D 301 – D 304	LED LD 350-4
1	D 306	Diode HSCH 1001
4	I 301, I 302 I 307, I 308	TL 071 CP
1	I 303	LM 339 N
1	I 304	CD 4066 BE
1	I 305	NE 555
1	I 306	LM 311 N
1	I 309	MC 7808 CT
1	I 310	MC 7908 CT
1	R 312	Resistor 62 Ω
4	R 301, R 304 R 319, R 320	Resistor 100 Ω
1	R 325	Resistor 220 Ω
4	R 309, R 310 R 313, R 314	Resistor 470 Ω
1	R 324	Resistor 1.2 kΩ
1	R 318	Resistor 3.3 kΩ
1	R 308	Resistor 1.8 kΩ
1	R 322	Resistor 3 kΩ
1	R 315	Resistor 3.9 kΩ
1	R 321	Resistor 3.6 kΩ
10	R 307, R 311, R 316 R 326, R 302, R 303 R 305, R 306, R 327 R 328	Resistor 10 kΩ
1	R 317	Resistor 12 kΩ
1	R 323	Resistor 100 kΩ
1	R 329	Resistor 1 MΩ
1	C 305	Capacitor 100 nF / MKS
19	C 301, C 302, C 304 C 307, C 308, C 309 C 310, C 311	Capacitor 100 nF / ceramic
1	C 303	Capacitor 150 nF / MKS
1	C 306	Capacitor 1 μF / MKS
2	C 312	Capacitor 10 μF, 16 V / tantalum
1	C 313	Capacitor 3.3 nF / FKC
3	P 301, P 302, P 306	Potentiometer 100 kΩ
1	P 303	Potentiometer 2.2 kΩ
1	P 304	Potentiometer 470 Ω
1	P 305	Potentiometer 100 Ω
1	S 301	Switch SBL 11/1/4x3
1	S 302	Toggle change-over switch M90-3A
1	–	31-pole connector DIN 41 617
1	–	Front panel 1 inch Vero F1V1F
2	–	Telephone connector, insulated
1	–	Knob for 6 mm dia. shaft
2	–	Mica disks for TO 220
–	–	Solder pins
–	–	Screws and nuts
1	–	PC-board DL0HV 003, 100 x 160 mm, double-coated

Testpoint 8 is grounded for the offset alignment of I 307; P 306 is then aligned so that the voltage at testpoint 9 is set to 0 V.

The next step is to test whether a square-wave signal with a keying ratio of 4.5:1 and a frequency of approx. 750 Hz is available at the output of I 305 (TP 5).

In switch position 3 or 4 (S 301), it is necessary for the offset of the comparator to be aligned with the aid of potentiometer P 303. This is made by connecting a DC-voltage of 1 V to connection 24, and a voltage of 0.5 V at connection 25. This represents a gain of 6 dB and a logarithmic output voltage of 0.4 V. Any deviation can be corrected with the aid of P 304. After this, connection 24 is provided with a DC-voltage of 300 mV and a voltage of 150 mV fed to connection 25. This also corresponds to a gain of 6 dB. P 303 should now be aligned for an output voltage at TP 9 of 0.4 V.

This procedure should be repealed alternately until no deviations are observed. Finally, it is only necessary for the output voltage of I 308 (TP 11) to be aligned with the aid of P 305 to 0.2236 V (0 dB).

Comparative experiments made with this logarithmic circuit and another constructed according to Tietze/Schenk (page 209, Fig. 11.22) show that high accuracies were achieved with both types.

However, the described circuit exhibited better temperature drift characteristics that were at least one order of magnitude better. Furthermore, the alignment is considerably easier.

7. SPECIFICATIONS

Power Supply: 220 V/50 Hz

Voltages for the modules: ± 12 V unstabilized
± 8 V stabilized

Measuring ranges: 1 mV to 10 V in nine ranges

Maximum DC-voltage component at the measuring probe: 40 V.

RMS-value indication in the case of sinewave voltages

Frequency range:
Through-probe: 1 MHz – 1.3 GHz
Test probe: 10 kHz – 1.3 GHz

Error limits:
Operating module with AF-module: <1%
Logarithmic circuit: <0.1 dB

Through-probe
(AA 119): <10% up to 500 MHz

Test probe
(AA 119): <10% up to 500 MHz

Impedances:
Through-probe: 60 Ω
Test probe, 10 MHz: >80 kΩ/2.5 pF

DC-voltage output:
For analog meter: 0...+1 V
For digital meter: 0...+0.316 V/1 V

Transcient time: 1 s

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